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Standard Guide for Use of the Steam Stripping Process in Mitigating Chemical Spills¹

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1. Scope

1.1 This guide covers the considerations for the use of steam stripping in the mitigation of spilled chemicals (including hydrocarbons) dissolved in ground and surface waters. Aesthetic and socioeconomic factors are not considered; although, these and other factors are often important in spill response.

1.2 This guide addresses the application of steam stripping alone or in conjunction with other technologies.

1.3 In making decisions with regards to discharging treated water and operating a boiler, appropriate government authorities must be consulted as required by law.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* In addition, it is the responsibility of the user to ensure that such activity takes place under the control and direction of a qualified person with full knowledge of any potential or appropriate safety and health protocols.

2. Terminology

2.1 Definitions:

2.1.1 *feed-to-steam ratio*—ratio of feed flowrate (by weight) to steam flowrate (by weight).

2.1.2 *foulants*—substances, such as clay or silt, microbial biomass, organic solids or film, inorganics, and naturally occurring compounds, that interfere with the desired process.

2.1.3 *Henry's law*—when a liquid and a gas are in contact, the weight of the gas that dissolves in a given quantity of liquid is proportional to the pressure of the gas above the liquid. The law holds true only for equilibrium conditions, that is, when enough time has elapsed so that the quantity of gas dissolved is no longer changing.

2.1.4 *Henry's law constant*—a function of the compound's solubility in the liquid phase and its volatility. A high Henry's law constant indicates equilibrium favoring the gas phase, that

is, the compound is more easily stripped from water than one with a low Henry's law constant. Theoretically, Henry's law constant can be estimated from vapor pressure, solubility, and molecular weight as follows (1):²

$$HC = \frac{V_p \times MW \times 16.03}{sol \times T} \quad (1)$$

where:

HC = Henry's law constant (atm m³ water/m³ vapor),

V_p = vapor pressure (mm Hg),

MW = molecular weight (g/mole),

sol = solubility (mg/L), and

T = temperature (K).

2.1.5 *inorganic foulants*—compounds, such as those of iron, calcium, and manganese, which precipitate in a treatment unit, thereby reducing the throughput and efficiency of the process.

2.1.6 *packing*—is placed in a stripping column to increase the available surface area for mass transfer.

2.1.7 *pH*—a measure of the acidity or alkalinity representing the logarithm of the reciprocal of the concentration of hydrogen ions.

2.1.8 *purge and trap technique*—uses an inert gas (such as helium or nitrogen) to purge the compounds into a gaseous state.

2.1.9 *removal efficiency*—

$$\frac{[\text{inlet contaminant}] - [\text{outlet contaminant}]}{[\text{inlet contaminant}]} \times 100 \% \quad (2)$$

2.1.10 *semi-volatile organic compound*—a compound that is amenable to analysis by extraction of the sample with an organic solvent. It is used synonymously with Base/Neutral/Acid (BNA) compounds.

2.1.11 *steam stripping*—a separation process that utilizes differences in the thermodynamic properties of liquids. In this process, steam and organic-contaminated water are fed counter-currently to a packed column, causing the transfer of the contaminant(s) from the water phase to the vapor phase. The driving force for the separation is the concentration differential of the organic component(s) between the liquid and vapor phases. Two streams are generated in this process,

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

namely: bottoms (treated effluent) and tops or overhead (concentrated contaminant).

2.1.12 *equilibrium vapor pressure*—the pressure at which, at constant temperature, a pure substance's vaporization, and condensation rates are at equilibrium.

2.1.13 *volatile organic compound*—a compound amenable to analysis by the purge and trap technique. It is used synonymously with purgeable compounds.

2.1.14 *volatility*—the tendency of a solid or liquid material to pass into the vapor state at a given temperature.

3. Factors

3.1 Removal efficiency is highly dependent on the properties of contaminants, such as Henry's law constant and vapor pressure, and the system operating parameters, such as temperature and steam-to-water ratio. An increase in any of these parameters or properties produces a corresponding increase in removal efficiency, assuming all other factors remain constant.

3.2 Other factors that influence removal efficiency include the size and type of column packing and the ratio of column diameter to packing diameter. In addition, the presence of solids will cause fouling that would reduce the throughput of the unit and could affect organic removal efficiency.

3.3 For compounds less volatile than water, the ability to form minimum boiling azeotropes or heteroazeotropes is considered indicative of good potential for steam stripping. In these mixtures, heating a dilute solution will result in a vapor phase richer in the contaminant even though the contaminant has a lower vapor pressure than water. The azeotrope will prevent production of a pure overhead stream. Since the objective is only to purify the underflow, this is not a problem.

4. Significance and Use

4.1 The purpose of this guide is to provide remediation managers and spill response teams with guidance on the use of steam stripping, to safely and effectively reduce environmental impacts of hazardous spills (chemical and oil) on water. Steam stripping is one of many available tools and may not be applicable to all situations.

4.2 Steam stripping technology has been used extensively in the chemical process industry; however, it is only in recent years that it has been applied in the remediation of contaminated water. For this reason, this guide will only refer to those units that are presently used in the field for that purpose.

4.2.1 This technology is especially attractive to contaminated industrial sites where surplus steam supplies are available.

4.3 This guide can be used in conjunction with other ASTM guides addressing hazardous (chemical and oil) materials spill response operations.

4.4 The steam stripping process may be applied alone or in conjunction with other treatment techniques as described in 4.5 and 4.6.

4.5 Steam stripping may be used following a pretreatment step, which will provide a method, either physical or chemical, for the removal of foulants from the contaminated stream prior to steam stripping. If these foulants are not removed, the throughput and efficiency of the process will be significantly reduced.

4.6 Steam stripping may be used to concentrate a dilute contaminated stream so that it may be treated more cost effectively at a higher concentration with another technology.

5. Constraints on Usage

5.1 Literature searches on the predicted removal efficiencies are essential prior to field scale treatment. Bench scale testing should be done where complex mixtures are present or behavior cannot be calculated by theory.

5.2 The nature and concentration of contaminant will affect the overall system performance. In general, organic compounds with higher Henry's constant are more easily stripped.

5.3 Generally, inorganic foulants, such as iron, calcium, and manganese, in the ppm range, reduce throughput and efficiency of the process. This phenomenon is common in most organic treatment units regardless of the mechanism employed. Generally, pre-treatment systems involving chemical addition (that is, pH adjustment) or membrane technology, or both, are the most economical and effective for inorganic removal. Although, in some cases, the change in pH can affect the removal efficiency.

5.4 Steam stripping must be carried out under the guidance of qualified personnel that understand the contaminant, process, and safety and health aspects of site activities.

5.5 Steam stripping cannot remove certain compounds, such as: acetic acid, glycols (ethylene or propylene), glycerine, sulfonated organics, and inorganics (except in free gaseous dissolved form, such as ammonia and carbon dioxide).

5.6 Some phenols can be steam stripped; however, it is normally not cost effective due to the large amount of steam required for the process.

6. Field Scale Results Using Steam Stripping

6.1 Table 1 lists some results of testing the removal of specific compounds by steam stripping at the field scale.

7. Recommendations

7.1 Steam stripping should be considered as one of the potential treatment methods available to site remediation managers once the spill has been contained and gross quantities of contamination have been physically removed.

7.2 Steam stripping should only be performed with technically-qualified personnel, following health and safety protocols for such activity.

7.3 Before steam stripping is carried out, the technology's potential for removing the contaminants in question should be reviewed in terms of its efficacy based on a literature search and data supplied by the stripping system manufacturer. Bench scale confirmation on such contaminated water would also be desirable. System operating parameters should be optimized during the first few days of operation.

7.4 In order to measure the success, a rigorous monitoring program should be established to determine the contamination levels, track the contamination plume, and analyze the treated effluent stream. This effluent should be sent to a holding tank prior to ultimate disposition (for example, reinjection) so as to ensure that the water discharged is in accordance with regulations. Furthermore, the contaminated concentrated stream must be managed in an appropriate manner.